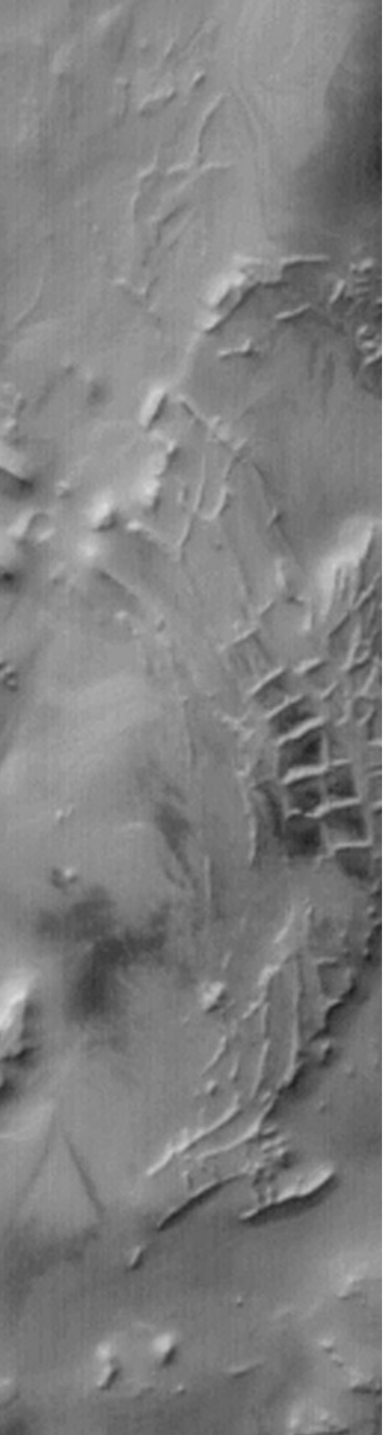

Enhancing Space Operations Workshop
Best Practices Track

NASA Lessons Learned: Moving to a More Formal Process

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Introduction

- Why is NASA placing a renewed emphasis on lessons learned?
  - Repeated mistakes, or violation of known best practices, pose a risk that is potentially avoidable
    - "*Progress, far from consisting of change, depends on retentiveness... Those who cannot remember the past are condemned to repeat it*."

      -George Santayana
    - *"An expert is someone who knows some of the worst mistakes that can be made in his subject, and how to avoid them."*

      -Werner Karl Heisenberg
  - Diaz Report assessed the agency-wide applicability of the CAIB report
    - "… require that everyone understand their responsibilities and are given the authority to perform their jobs, with the accountability for their individual and program's successes and failures, including lessons learned." (Page 10)
    - **"**The CAIB concluded NASA 'has not demonstrated the characteristics of a learning organization' after investigators observed mistakes being repeated and lessons from the past apparently being relearned." (Page 11)
  - Opportunity to add more rigor to the NASA lessons learned process

Introduction (Continued)

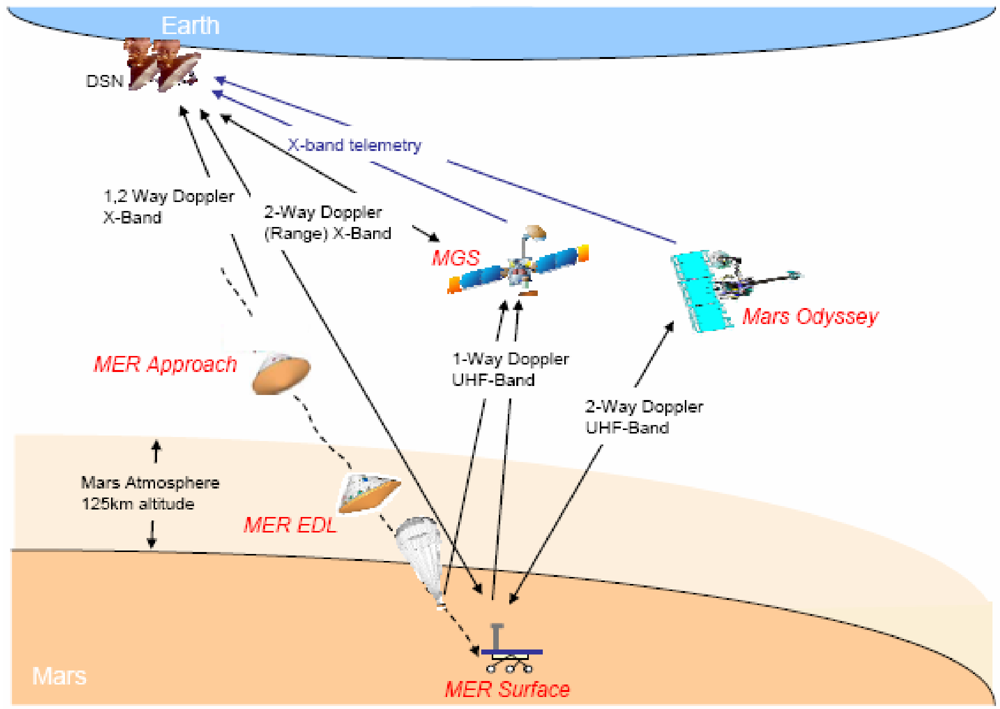
- The JPL programmatic environment fosters an emphasis on effective best practices and lessons learned processes
  - JPL focus on high risk flight projects (novel capabilities, long duration, extreme environments, decreased development time, special space ops)
  - Recent change in the project mix from developing a single flagship mission (Voyager, Cassini), to design and operation of 40 flight projects
  - Each project is a relatively unique, one-of-a-kind product, in terms of both system and mission design
  - Gradual loss of institutional knowledge base
  - JPL reorientation toward a procedure-based design process

The NASA Lessons Learned System

- Establish effective processes for capturing and integrating lessons learned/best practices information
  - An "Effective" Process: One that solicits, documents, and infuses lessons learned throughout the Center and NASA in a manner that will lead projects away from critical errors, or toward critical project success factors, encountered by their predecessors
- NASA has maintained a lessons learned system since 1992
  - NASA Lesson Learned Information System (LLIS) has 1500 lessons, an advanced search capability, and is accessed 2500 times per month
  - One to two-page lessons with 2 or 3 actionable recommendations. Some lessons learned document "positive" events.
- NASA *Preferred Practices for Design and Test* focus on proven system development techniques
- Center-centric: lessons learned system permits NASA field centers to employ processes and issue lessons and practices suited to Center needs

Provide In-Flight Capability to Modify Mission Plans During All Ops

Both the Mars Exploration Rover (MER) flight system and mission designs had the flexibility to react to unexpected events. The MER flight system provided an in-flight capability to revise Entry, Descent and Landing (EDL) parameters by coding them in flight software. The MER mission design provided an operational plan, process, and tools permitting JPL to perform EDL parameter updates over a span of several days during final approach to Mars and up to six hours before landing.



MER Encounter Communications Links

Sample Ops Lesson Learned (Cont.)

Provide In-Flight Capability to Modify Mission Plans (Continued)

The ability to update EDL parameters was critical to the success of the MER mission. Updated data on Martian atmospheric pressure received from the Thermal Emission Spectrometer (TES) instrument on the Mars Global Surveyor (MGS) spacecraft during final approach (see figure) indicated a lesser atmospheric density than expected. Left uncorrected, the actual lesser atmospheric density could have caused MER to sense its dynamic pressure target at a lower altitude than planned, and to trigger its parachute deployment too near the ground. Because the flight team had the processes for changing EDL parameters, and the ability to modify these parameters after launch, the timing of the MER parachute release was successfully accomplished.

Lesson Learned:

Critical parameters coded in flight software and the ability to alter them within hours of critical events in response to unexpected data on flight characteristics can save a planetary mission or deep space encounter.

Recommendations:

For spaceflight missions-- particularly landers-- ensure that the flight system and mission designs and have flexibility to react to unexpected events:

1. **Code critical parameters in flight software.**
2. **Maintain an operational capability to update these parameters during the latter stages of encounter/EDL.**

Incentives for Process Improvement

- The cost to NASA of a critical error mandates some assurance that critical lessons are identified and are actually learned
- NASA and the Centers have employed, for the most part, an ad hoc lessons learned process
  - Lack of a formal, controlled process can lead to ineffective NASA-wide coordination, and ineffective Center solicitation and prioritization of candidates, status tracking, review/approval, dissemination, etc.
- GAO Report GAO-02-195, *Better Mechanisms Needed for Sharing Lessons Learned*, January 2002
- CAIB findings tend to reinforce those issued earlier by GAO
- NASA recently issued NPR 7120.6, *The NASA Lessons Learned Process*
  - Establishes basic NASA requirements for the collection, validation, assessment, codification, and infusion of lessons learned that are critical to mission success

Example LL Process Issues

- Establish criteria for an effective lessons learned process
  - How does the enterprise plan the acquisition of lesson material?
  - How are lesson candidates currently validated?
  - How is lesson generation coordinated and managed?
  - How are lesson drafts edited, reviewed, and approved?
  - Is the lesson approval process sufficiently rigorous to prevent backlash?
  - How are lessons learned disseminated throughout the enterprise ? How do you judge their impact?
  - How do lesson recommendations engage the enterprise's closed-loop corrective action process?
  - How are lessons learned infused into procedures and training.
- Workshop participant input on key criteria

Elements of a Formal LL Process

- NPR 7120.6: There is a range of activities that defines an effective lessons learned process

Enterprise-wide process flow (JPL example)

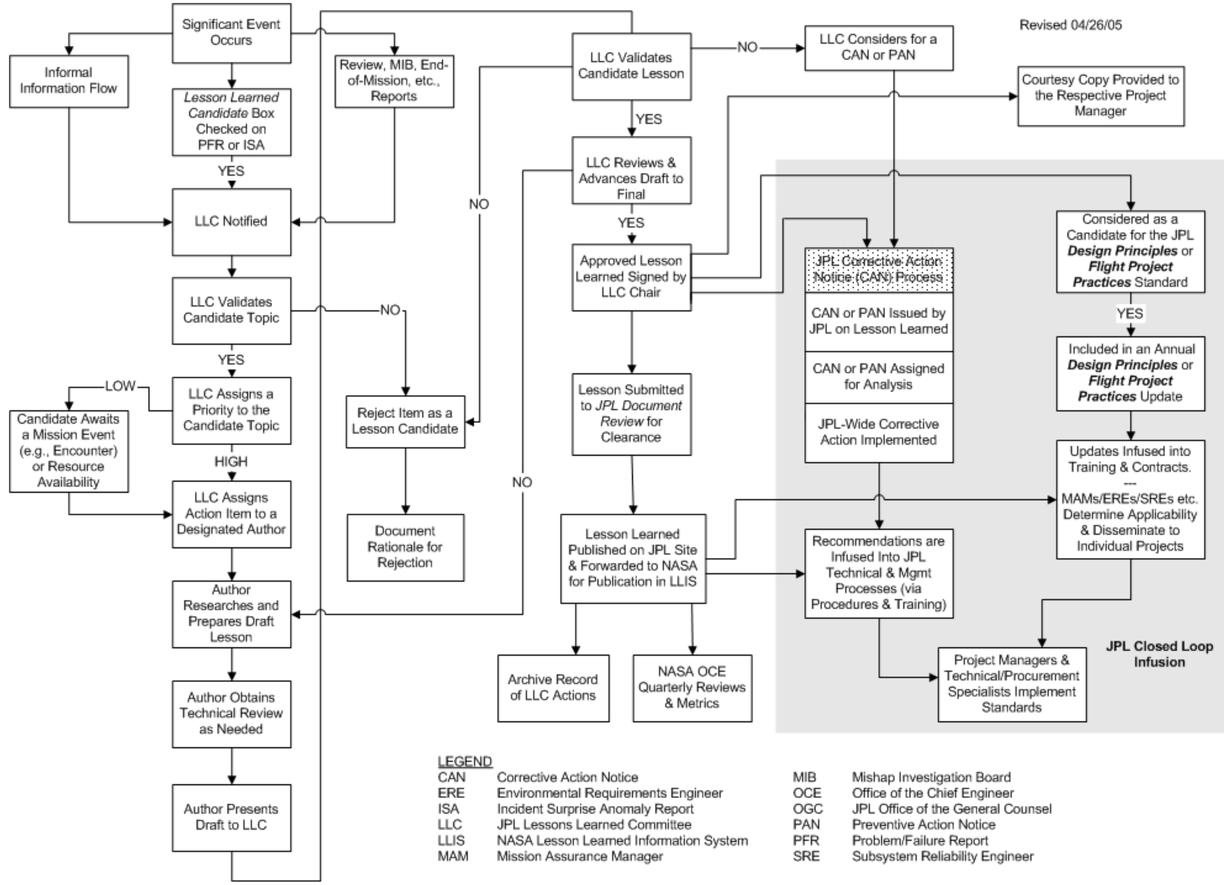


Figure 1. Lessons Learned Process Flowchart

Elements of a Formal Process (Cont.)

- NPR 7120.6: Charter a Lessons Learned Committee (LLC) with a central role in the collection and processing of lessons learned

JPL example: lessons learned process description has been incorporated into a JPL requirements document

MY RULES ADD TO MY RULES SEARCH GO CONTACT US HELP LOG OUT
Rules!
Welcome, David J Oberhettinger

DOCUMENT DETAILS | SEND COMMENTS | INCLUDE TABLE OF CONTENTS | NOTIFY ME

OFFICIAL
Standard

Lessons Learned Requirements (D-15553), Rev. 3
Effective: Nov 27, 2001

DocID 35531

Document Owner: Dudley Killam

Introduction

The engineering and operation of extremely complex systems is naturally prone to error. No single person can maintain cognizance over the design of all spacecraft systems, nor over all inherited components, materials, and processes from prior programs. The potential for errors in engineering judgement presents an especially high level of mission risk when applied to planetary spaceflight, with its very limited opportunities for corrective maintenance. JPL succeeds in deploying reliable systems through robust design; however, the organization is heavily dependent on its experience base to identify necessary design margins and resolve latent defects. The JPL lessons learned process provides a method of assuring project access to this experience base.

Applicability

This applies to all JPL project and program offices and personnel responsible for development of flight hardware and software.

Purpose and Scope

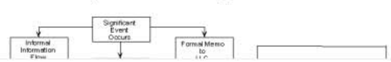
A lessons learned process has been established by JPL to provide a formal record of lessons learned. The objective is to advance JPL missions by exposing personnel to significant events from which important "lessons" can be drawn which have applicability beyond the original event. Although these lessons may be incorporated into JPL and NASA standards, they are retained and widely circulated the NASA-wide *Lessons Learned Information System* (LLIS).

The scope of this effort is limited to documenting events arising out of, or related to, the implementation and operation of flight and related support equipment. To this end, the LLIS is designed to use established problem/failure and discrepancy reporting systems to identify and document lessons. Events are evaluated for their suitability as lessons based on the:

1. Significance in terms of actual or potential project impact, including effects on project success, cost, schedule, safety, public visibility, or management visibility.
2. Importance to future JPL activities. This may include events of non-JPL origin, and
3. Lack of prior coverage of the event or underlying issue(s) in previously approved lessons or other closed loop alert processes.

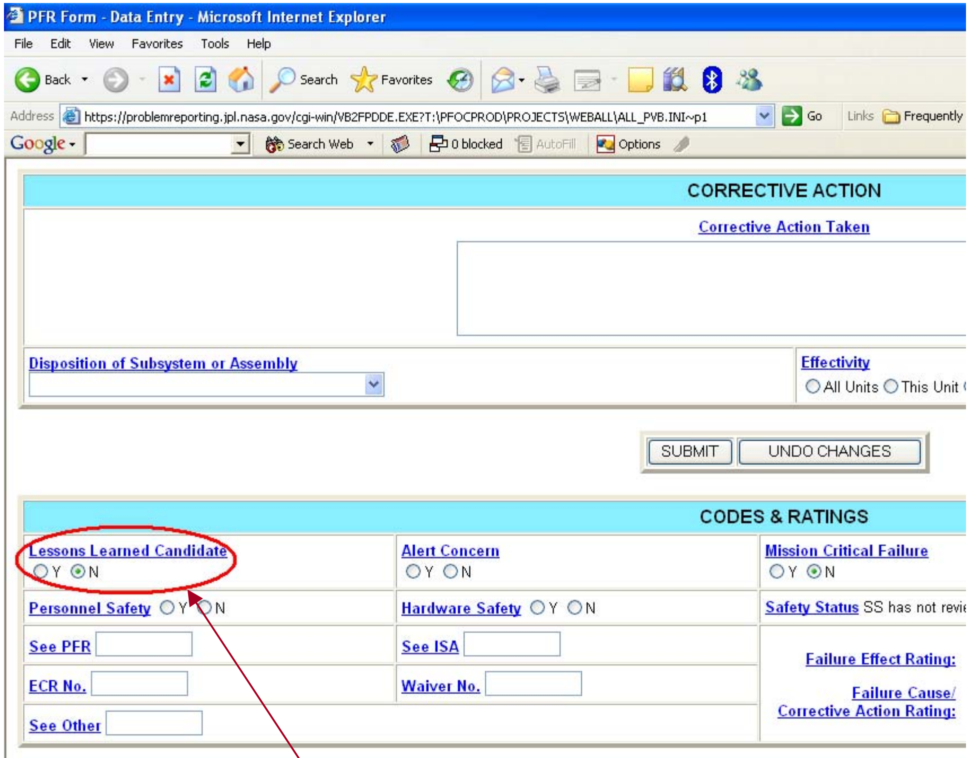
In response to calls for JPL to innovate at an increased pace and to better quantify levels of mission risk, the organization has renewed its commitment to maintaining and augmenting its corporate knowledge base. The LLIS is an important element of this knowledge base-- a searchable collection of discrete lessons judged applicable to current and future NASA missions. Prior to implementation of this system, information on critical success factors was communicated informally on a hit or miss basis. The identification, documentation, dissemination, and use of this information provides a valuable risk management tool. Approved lessons learned also provide inputs to the JPL corrective action system, assuring closed-loop resolution of JPL-wide problems.

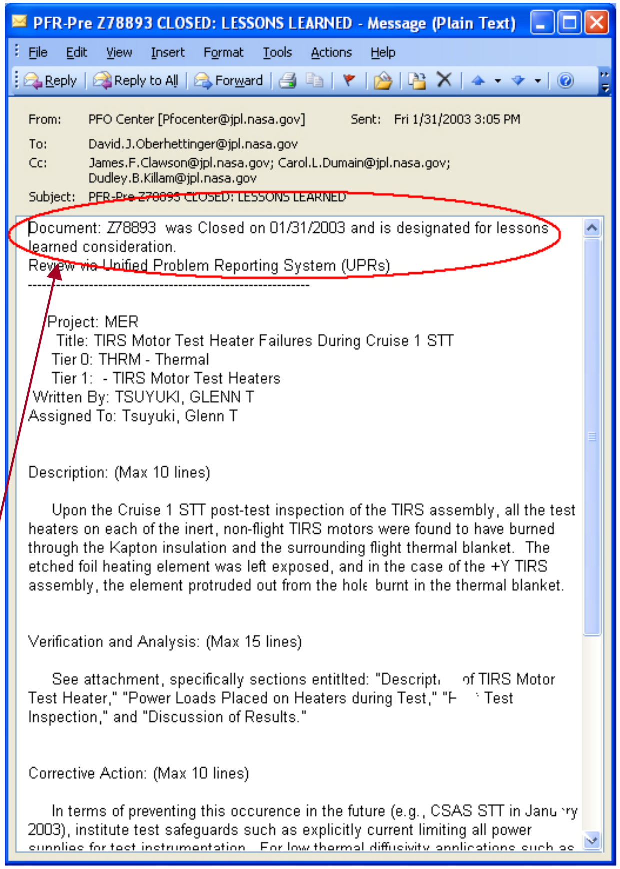
JPL has established the following process, as outlined in Figure 1, for ensuring that critical lessons, once learned by the organization, do not have to be relearned.



Elements of a Formal Process (Cont.)

- NPR 7120.6: The LLC procedures should provide for active solicitation of lessons learned material
  - Active vs. passive modes of LLC outreach





Checking the *Lessons Learned Candidate* box on the failure report form (circled on the left) generates an automatic e-mail notification (on right).

Elements of a Formal Process (Cont.)

Jet Propulsion Laboratory
California Institute of Technology

Office of the Chief Engineer

- Review significant events for their candidacy as lessons learned
  - JPL reviews and prioritize candidate lessons based on their applicability to current and future projects

Microsoft Excel - PFR_Matrix_2005-04-04.xls:1

K65 # 1358

PFR/ISA No.	Date Initiated	Date Closed	Project	LL Candidacy Reviewer	Description (red font indicates an open PFR / ISA)	Verification & Analysis (red font indicates an open PFR / ISA)	Corrective Action / Lesson Learned Preliminary Assessment / Lessons Learned Validity	Lessons Learned Committee Action: Considered	Applicable	LL Written
Z78893	12/30/2002	1/30/2003	MER	Tsuyuki, G	Upon the Cruise 1 STT post-test inspection of the TIRS assembly, all the test heaters on each of the inert, non-flight TIRS motors were found to have burned through the Kapton insulation and the surrounding flight thermal blanket. The etched foil heating element was left exposed, and in the case of th +Y TIRS assembly, the element protruded out from the hole burnt in the thermal blanket.	See attachment, specifically sections entitled: "Description of TIRS Motor Test Heater," "Power Loads Placed on Heaters during Test," "Post Test Inspection," and "Discussion of Results."	3/17/03 LLC Mtg: This report is a valid lesson learned candidate because of the likely consequences if the damage had not been noticed. This candidate has been assigned a high priority (10) by the LLC. The recommendation will be drawn from the "test safeguards..." issue. In terms of preventing this occurence in the future (e.g., CSAS STT in January 2003), institute test safeguards such as explicitly current limiting all power supplies for test instrumentation. For low thermal diffusivity applications such as the TIRS motors, the test thermocouple should be placed directly on or adjacent to the test heater. The test heater failure only damaged flight TIRS thermal blankets. These blankets will be refabricated and reinstalled prior to flight. The TIRS motors were inert units so the motors and their associated thermal hardware are non-flight. The flight heater kits were unaffected.	--	Yes	# 1358
Z78830	12/19/2002	3/24/2003	MER	Sevilla, D	During MER 2 surface thermal testing the left and right side rocker-differential microswitches changed state from "closed" to "open" during the bogie deploy portion of the test (NEED TO VERIFY TIMING RELATIVE TO WHEEL MOTION) The full order of events was as follows: Rover lifted, rockers deployed, rover lowered (rocker-differential microswitches changed state from OPEN to CLOSED, as they are supposed to, during lowering), the tilt and rocker-diff microswitch tests passed, the RLM was retracted fully, and then the bogies were deployed	After the rover is taken out of the chamber we will need to verify that the latches are still fully engaged (likely since vehicle is stable and has not collapsed) and that it is just a microswitch positioning problem. See also PFR Z78233, rocker-diff latch microswitch failure during mobility testing ------------------------------ ------------------------------ 03/05/2003 The right and left MER2 RDA microswitches were inspected on 2/5/2003 following AIDS #238398. They were both found to have	Not a lesson learned candidate; Lesson # 0289 generally covers the design issue of marginal microswitch actuation. (D. Oberhettinger 6-7-04) 03/05/2003 The right and left MER2 RDA microswitches were inspected on 2/5/2003 following AIDS #238398. They were both found to have essentially zero micrositch margin. Both were adjusted to product a .003" microswitch margin. The MER2 rover went through a second STT from Feb. 5-6, 2003. There were no anomalous RDA microswitch readings during that test. Note: The MER1 RDAs were adjusted and tested in a similair manner (AIDS #238546). No	No	No	

JPL maintains a spreadsheet that documents LLC action on candidates forwarded by the problem/failure reporting system

JPL LLC formally reviews failure reports designated as lessons learned candidates, and documents its findings.

- NPR 7120.6: Validate lessons learned with subject matter experts

JPL LESSONS LEARNED COMMITTEE
Lesson Learned Candidate List
4/5/05

JPL LLC maintains a lesson candidate/status list

Event	*Rank	Point of Contact	Notes / Status
1. If a Command References an Incorrect Transaction Request File (TRF) Name, the Command Will Be Ignored		Tim Larson	Tim Larson reports (4/5/05 D.K. e-mail[A1]) a lesson learned for other projects using CFDP for uplinks—ensure that all the ground tools and testbeds enable checking of these CFDP unique files. (Tim Larson to report at LLC meeting.)
2. MER pixel corruption	D	PFR Z77062[A2] LL Candidacy Reviewer: M. Schwochert	The LLC approved this as a candidate in its review of PFR Matrix. D.O. Comment: a CAN assigned to Div 800 may be more appropriate than an LL, as this is a very detailed camera design issue. **4/4/05 LLC Mtg**: deferred this topic to a PAN, with action item assigned to J. Krueger
3. Deep Impact High Resolution Instrument focus (placeholder)	P	PFR Z85620	This candidate is deferred until a failure investigation is completed
4. Beagle 2 Commission of Inquiry: Recommendation 16	9	Lincoln Wood, Wyatt Johnson, Joe Guinn	http://www.spacedaily.com/news/beagle2-04g.html "A back-up for the entry detection event (T0) must be included in the design of planetary entry probes." Wyatt Johnson e-mail of 11/22/04: The MSL (Phase A) current chute deploy method is a g-trigger, with an IMU-navigated velocity trigger as a back-up. David O: This may represent a candidate for a positive LL. Aron Wolf concurs, but opines that this should not be linked to Beagle 2. **3/14 LLC mtg:** This issue is closely related to the "negative" LL on the Genesis mission failure, and hence should await issuance of the Genesis MIB report.

*Rank: 1-9 Priority (9 being the highest priority), P=Pending, D=Deferred   Completed or invalidated candidates are moved to the Retired Candidate List.

JPL LLC tracks the status of lessons learned candidates from all sources and assigns a priority to each.

Elements of a Formal Process (Cont.)

- Evaluate lessons learned submissions and develop a final lessons learned draft that includes actionable recommendations

- What methods have the workshop participants found successful in obtaining timely draft lessons?
  - Who writes them: the person who proposed the topic, a single author/editor on staff to the LLC, a combination (i.e., author interviews the proposer)?
  - Who reviews the drafts, and how are conflicts resolved?

- What type of recommendations are appropriate and useful?
  - Propose solutions that are actionable, that the user should consider, but not “obvious” or presumptuous or held to be always applicable

Actively Manage Flight Project Risks During the Operations Phase

Cassini is one of the first major JPL missions to successfully conduct a risk management program during the Mission Operations and Data Analysis (MO&DA) phase, in addition to the normal system development program. When the risk management program was revived 3 years after the 1997 launch, the Mission Operations System (MOS) Team viewed it as a new and challenging practice. Implementation was complicated by the distribution of the 500-person MOS Team across the U.S. and Europe, involving over 16 sub-teams, 9 time zones, and information exchange limitations mandated by International Traffic in Arms Regulations (ITAR).

To plan the risk management process for MO&DA, training workshops and tutorials were held during 2000, and a risk management plan and schedule were issued in early 2001. Subsequent brainstorming sessions produced a Significant Risk List (SRL), risk items were sorted by mission phase, and they were documented in an on-line tool and categorized according to likelihood and impact. A Risk Team met quarterly to review the project’s risk posture, add risk metrics to the on-line tool, and brief the MOS Team and NASA. The risk posture was a standard briefing topic at Cassini readiness reviews and monthly management reviews.

A key to the success of this program was deferring wider participation (e.g., ESA, Instrument Team) until the risk management process was well established and understood by the JPL MOS Team. Once an on-line tool and risk performance metrics had already achieved a measure of acceptance at JPL, participation by the European Space Agency and the Instrument Team was solicited. With these tools in place, changes in the project risk profile became easily visible to the MOS Team and Cassini project management.

Example "Positive" LL (Continued)

Actively Manage Flight Project Risks During Ops (Continued)

Lesson Learned:

Cassini demonstrated that active management of risks can be implemented effectively during mission ops despite the need to involve a large, geographically distributed, MOS organization

Recommendations:

1. Implement a formal risk management process during MO&DA that is tightly scoped to the operational phase (i.e., Cruise, Tour, Orbit Insertion, Probe Mission).
2. Define the scope of the risk management program early in the MO&DA phase, obtain project manager endorsement to encourage MOS Team acceptance, reassess risks at appropriate milestones, and continue the process until end-of-mission.
3. Adopt a flexible risk management database tool that is compatible across platforms and clearly depicts the project's evolving risk posture.
4. The risk management process should include attention to human performance factors (stress, fatigue, health, work schedule, etc.) during mission operations.

Elements of a Formal Process (Cont.)

– NPR 7120.6: A lessons learned infusion process is required to 'close-the-loop' on actionable lessons learned recommendations

JPL tracks the status of each recommendation (which may be assigned to multiple JPL processes)

	A	B	C	D	E	F
1	LL No.	Lesson Learned Title	Process Assigned	Recommendation	Lesson Learned Summary & Recommendations Related to Process	Disposition of LL Recommendation
2	307	Anomalous AMPTE/CCD Command Counter Readings	DPS	1	Five times during one month the "Unexecuted Command Counter" value was anomalous. Possible causes included incorrect incrementing of the counter, incrementing due to noise, or commands that were rejected due to incorrect bit patterns. **The telemetry formats should be designed considering all potential analyses that may require time-tagged data.**	**Completed.** All DPS procedures must be required to conduct reviews of product design: see steps 3.8, 4.8, 5.8 and 6.3 in the Design Product Systems: Flight Subsystem/ Instrument Design- Doc ID 57396. -M. Jahan (file: LL for DPS OPS Disposition-051304.xls), 5/18/04
3	307	Anomalous AMPTE/CCD Command Counter Readings	DSP	1	Five times during one month the "Unexecuted Command Counter" value was anomalous. Possible causes included incorrect incrementing of the counter, incrementing due to noise, or commands that were rejected due to incorrect bit patterns. **The telemetry formats should be designed considering all potential analyses that may require time-tagged data.**	**Transferred.** Add [also] to Software LL list. -M. Jahan (file: LL for DPS OPS Disposition-051304.xls), 5/18/04
4	308	Solder Balls in Flight Modules	APQ	1	Because a design change had been made to the proven Mariner design, the Viking orbiter flight radio modules developed short circuits caused by solder balls shorting terminal lugs to ground. **Before making design changes, related applications should be reviewed for known problems with this solder ball effect. Evaluate each design to determine whether solder can flow into uninspectable areas.**	**Completed.** Covered by D-1348 Sect 3.11@2.8 & 3.2.1. -C. Kingery, 6/9/03
5	310	Mars Observer Inertial Reference Loss	DSP	2	Mars Observer experienced inertial reference loss on several occasions during its cruise to Mars. These incidents were due to the lack of a detailed code walk-through, and to use of gyro noise values, obtained from in-house test, that were more optimistic than the manufacturer's specifications. **2. Perform detailed code walk-through of critical software modules, and particularly of flight software patches.**	**Completed.** D-23713 (Para 3.3.4), Rev. 4 has been amended to state, "A detailed code walk-through should be performed on post-launch changes (or patches) to critical flight software modules." -per J. Hackney - 8/26/03
6	310	Mars Observer Inertial Reference Loss	DSP	3	Mars Observer experienced inertial reference loss on several occasions during its cruise to Mars. These incidents were due to the lack of a detailed code walk-through, and to use of gyro noise values, obtained from in-house test, that were more optimistic than the manufacturer's specifications. **3. Special attention should be paid to flight critical software performance that is inherited from previous applications. Prior anomalies must be addressed.**	**Completed.** D-23713 (Para 4.2.4), Rev. 4 has been amended to state, "Reviews of inherited code should address any known liens or defects as well as proper functionality." -per J. Hackney - 8/26/03
7	310	Mars Observer Inertial Reference Loss	DSP	4	Mars Observer experienced inertial reference loss on several occasions during its cruise to Mars. These incidents were due to the lack of a detailed code walk-through, and to use of gyro noise values, obtained from in-house test, that were more optimistic than the manufacturer's specifications. **4. Allow sufficient flexibility in the flight computer and software to permit necessary changes in flight.**	**Planned.** New - Add to SDP (reinstate old SW Dev Prin.)
8	310	Mars Observer Inertial Reference Loss	DSP	1	Mars Observer experienced inertial reference loss on several occasions during its cruise to Mars. These incidents were due to the lack of a detailed code walk-through, and to use of gyro noise values, obtained from in-house test, that were more optimistic than the manufacturer's specifications. **1. Do not depend on hardware performance being better than the manufacturer's specification.**	**Planned.** New addition will be made to Design Principle (SDP)
9	311	STS-56 High Rate Data Channel Failure Impact to ATMOS Experiment	ITMS	1	The high rate data channel for ATMOS failed. No complete end-to-end test had been performed either prior to or after the flight. **1. End-to-end tests must be performed.**	**Completed.** Fully infused by Doc ID 31432 (*Assembly Test and Launch Operations (ATLO), Rev. 3*), 3.2.1(6), Doc ID 31335 (*System Test and Launch Operations (STLO) Guide Executive Summary, Rev. 2*), IV.C.d & IV.C.f, Doc ID 35506 (*Anomaly Resolution (D-8091), Rev. 3*), 3.3.7, Doc ID 46792 (*System Test and Launch Operations (STLO), Rev. 0*), 4.3.4.2. -S. Barry Spreadsheet (ITMS_Lessons learned.xls), 5/28/04
10	311	STS-56 High Rate Data Channel Failure Impact to ATMOS Experiment	ITMS	2	The high rate data channel for ATMOS failed. No complete end-to-end test had been performed either prior to or after the flight. **2. Ensure that end-to-end tests to determine failure modes are performed prior to the disassembly of the payload.**	**Completed.** Fully infused by Doc ID 31432 (*Assembly Test and Launch Operations (ATLO), Rev. 3*), 3.2.1(6), Doc ID 31335 (*System Test and Launch Operations (STLO) Guide Executive Summary, Rev. 2*), IV.C.d & IV.C.f, Doc ID 35506 (*Anomaly Resolution (D-8091), Rev. 3*), 3.3.7, Doc ID 46792 (*System Test and Launch Operations (STLO), Rev. 0*), 4.3.4.2. -S. Barry Spreadsheet (ITMS_Lessons learned.xls), 5/28/04

Track the status of lessons learned infusion into Center-wide processes (procedures and training).

Summary

- Lessons learned document proven risks: the driving event it describes has occurred at least once, is significant, and may recur
  - Making the same critical mistake twice is distressing to the person and the institution
- NPR 7120.6 places new requirements on NASA and the Centers
  - Lessons learned must compete for the users' attention. A formal lessons learned process can help assure that valuable lessons get written and published, that they are well written, and that the essential information gets to the proper recipient when needed
  - An effective lessons learned system requires high-level Center commitment, and Center-wide participation in proposing, vetting, disseminating, and using the lessons
    - Project, line, and SMA organizations must be involved. A Lessons Learned Committee is needed to manage and coordinate the process
    - Effective dissemination and infusion of lessons learned is a major challenge